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MODELING NAVY SHIP ACQUISITION

FINAL REPORT FOR
PHASE II, PART 1

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1. INTRODUCTION

1.1 HISTORY AND STATUS OF THE PROJECT

This report presents the results of the work performed under Phase II, Part 1 of a three phase project being performed by The Analytic Sciences Corporation (TASC) under contract to the Office of Naval Research. The project's objective is to develop a computer-based planning model which will permit the Navy to achieve an efficient work load distribution in the shipbuilding industry through a competitive allocation process. The Phase I report, "Planning for Navy Ship Acquisition," (December 1978) presented the results of a feasibility investigation. Based upon the positive findings of this initial feasibility study, the Office of Naval Research has funded the initiation of Phase II.

As currently conceived, this project will be conducted in three phases: Phase I, preliminary analysis of model feasibility; Phase II, development of computer model; and Phase III, executive and analyst model development. Phase II is divided into three parts: Part 1, equation refinement and data search reported herein; Part 2, computer model development and data analysis, and Part 3, model check out, is proposed for performance in the year 15 November 1979 through 15 November 1980. The third phase, entailing the development of executive and analyst models in deliverable format, is planned to be conducted during the following year.

1.2 SUMMARY OF FINDINGS FROM PHASE I

TASC, during Phase I of this contract, performed a preliminary analysis of the cost and feasibility of developing a model to aid in achieving an efficient work load distribution in the shipbuilding industry through competitive allocation. This analysis included a detailed investigation of the planning and procurement methodologies currently used by the Navy as well as considering the feasibility of developing an analytic tool to aid the Navy in achieving an efficient work load distribution in the shipbuilding industry. This analytic tool, further elaborated here, models the interaction between the shipbuilding industry and the Navy. It is anticipated that the use of a computer model will permit consideration of both efficient labor and capital utilization in the shipbuilding industry, emphasizing the interaction of the industry with the Navy's budgeting, force planning, and procurement processes. Thus the model will provide decision makers with a tool permitting them to predicted results of different shipbuilding decisions thereby permitting consideration of a greater range of options.

In the conduct of this contract TASC reviewed the literature on the subject in some depth -- literature pertaining specifically to the shipbuilding industry as well as more general economic literature which portends to describe the a marketplace similar to the shipbuilding type. Extensive interviews of Navy and other government officials, executives of shipbuilding firms and other researchers were conducted. As a result of these efforts, TASC determined that a computer-based modeling approach was feasible, and its use would be expected to significantly improve the Navy's long-range planning for shipbuilding and provide specific guidance in its acquisition policy on a year-to-year and ship-to-ship basis with an objective of improved resource allocation.

For the present study, "competitive allocation" is the allocation among shipyards of a Five Year Plan which uses the price benefits of competition and the stability benefits of allocation to result in a shipbuilding program which results in minimum cost to the Navy, given other objectives and constraints such as suitable quality of products, attainment of schedules, and maintenance of industry capacity.

To demonstrate the feasibility of modeling competitive allocation, a preliminary model was designed. This model was based on the comparative efficiencies of individual shipyards and on their behavior in the marketplace. When fully developed, it will be a tool to inform the Navy of:

- The desired competitive allocation for Five Year and longer term plans
  - -- which distribution of work among yards costs the Navy the least?
- The acquisition methods needed to implement the competitive allocation
  - -- which yards are appropriate participants in competitions staged by the Navy?
  - -- which yards are appropriate candidates for allocations of ships?

Previous studies and interviews with people associated with the shipbuilding industry revealed that, while there is widespread agreement on the factors which affect the costs and delivery times of ships -- such as employment level and stability and quality of labor -- the interrelationships between these factors and relative magnitudes of their impacts are not explicitly defined. Thus, the model was developed so that historical data would test the magnitude of each factor's impact and the functional interrelationships of the factors.

As presented last year, the basic modeling approach uses three modules. The first module is the estimation of the relative cost of production in different yards. The second uses as input these relative costs, and information on the market strategies of the yards. It then estimates prices and price sensitivity of the Five Year Plan. The third is an executive module which controls the program, incorporates competitive effects and Navy decision criteria, and makes the least cost allocation. Each of these modules has been improved in its concept and equation form based on this year's analysis.

The cost estimation part of the model is an adjustment of the Navy's estimate of the basic cost to build a ship, as it is predicted to vary with individual yard characteristics. The specific variables, such as labor quality and supervisory experience, evolved from interviews and previous studies. The model was designed so that the value of each coefficient will be determined by historical data.

The price estimation module is based on: the yards' relative costs as revealed by the cost estimation; on the price benefits of competition; on the objectives, needs, and constraints of the Navy; and on the objectives of the yards and their gaming, or strategic behavior (as revealed by interviews, annual reports, etc). These aspects will be combined to find the allocation of work which will cost the Navy the least, and to show which yards are appropriate candidates for competitions for ships, and which yards are appropriate candidates for allocations of ships.

1.3 WORK PERFORMED DURING PHASE II, PART 1

Phase II, Part 1 was intended to provide continuing background analysis in order to refine the equation set, to

improve the validity of the analytic approach, and to demonstrate the feasibility of the data requirement for the model. During the course of this task, some specific background analyses were identified and performed in order to determine that the equation set properly captures the behavior of the industry as it is perceived at this time. Specifically, background analyses were performed on the following subjects:

1. The extent of planning problems which result from government furnished equipment, subcontracts and material
2. The influence of government procurement strategy and contract form on the price and competitive relationships
3. The importance of commercial production and repair and conversion with a view to proper incorporation of these effects in the model for Navy planning purposes
4. Further analysis of the nature of competition in the industry.

In addition to the performance of these specific background analyses, further work was done to place the modeling approach in a format suitable for full-scale computer programming development. The analytic approaches which been derived for the most important sub-routines have been programmed and checked out on a small scale computer. These specifically include the cost prediction module, the demand estimation module, and the optimization algorithm. A parametric study was performed using the cost model based upon postulated data. Results of this demonstration analysis are presented herein. The specific demand equations, derived for Bath and the two Todd yards, are representative of the FFG competitions which have taken place. Thirdly, the optimization algorithm using an extended Lagrange multiplier technique, was programmed and checked out to demonstrate its feasibility for this solution.

In view of the identified difficulties in demonstrating the feasibility of the data requirements, some specific work was performed to identify these. Formal requests were made for data from the FFG program as a test case. Despite some difficulties in bureaucratic and technical manipulation in order to secure this data, the data has been received by TASC and is now ready for further processing. Finally, the continuing interview process took place with Navy and industry personnel throughout the year to validate our modeling approach and to assure that our approach continues to represent the latest thinking concerning the behavior of the shipbuilding industry.

2. MODEL DEVELOPMENT

2.1 DESCRIPTION OF THE EQUATION SET

The equations describing the cost of producing a given ship at a given yard are essentially unchanged from those presented last year (Appendix A). The only equation in the cost model which has been changed is the equation for the yard employment level efficiency factor, called herein the "labor window." Last year this equation was presented in a piecewise linear form. For purposes of analytic tractability and as a result of discussions with the yards it is felt that a parabolic form is more appropriate. The following equation is therefore substituted for equation 7.1-11 in last year's report.

$$Y_i = 1 - \gamma_i (M_{oi} - M_i)^2$$

where

M_{oi} is the optimal employment level of the yard.

The major difference in the equation set as presented and developed compared to last year's report is that a more sophisticated analysis of the market has been performed. The Navy is assumed to have need for a given number of ships. However, the yards which are capable of producing these ships realize that they are in competition with the other yards, and therefore must adjust their prices in a manner which is dependent upon their estimate of the prices of the other yards. Analytically, this is expressed by assuming that the total quantity of ships which will

be purchased by the Navy is fixed, but the number that is going to be purchased from each yard is dependent upon that yard's price. The yard is assumed to be aware of the fact that the Navy has the option to buy ships from other yards, and is also capable of making an estimate of the prices that other yards charge. Each yard is therefore facing a downward-sloping demand curve for its product.

The yard is assumed to maximize some objective function subject to the fact that the demand for its goods does indeed have some elasticity. The objective functions which may be assumed include profit maximizing, cash flow maximizing, return of investment maximizing, as well as others. It should be noted that formulation of each yard's objective function agrees very well with the idea of limit pricing. The interpretation is that in a two yard case the low-cost yard knows that it is facing an extremely inelastic demand curve until it reaches a point where its price is now on the same level as the price of its competitors. Therefore, any objective maximizing function will necessarily result in a price which is very close to the price of the highest competitor.

The problem, of course, arises of how one would go about estimating the parameters which would determine the demand functions. In this section, we present an analysis which shows how, by using data which are available to the Navy, these demand parameters can be determined. Once the demand parameters are determined, it is possible to regress these parameters against factors which are known to be of significance in the market. This allows us to determine the quantitative impact of each of these parameters on what the yard perceives as the demand function for its goods. An equation will be put into the model which predicts the demand function facing each of the yards as a function of the parameters which would be known when the model is run. For

example, the number of competitors in the market, the total quantity of ships desired, the capacity available in each yard, etc. Once the demand parameters are known, it is simply a matter of plugging them into the objective maximizing function to determine what the yard will bid in a given situation.

In the next section we present the exact specification of how demand parameters can be determined and how the regression will be performed in order to determine which independent variables are significant in determining this demand parameter. It should be pointed out that preliminary analysis has shown a good statistical fit for the limited amount of data which is presently available when the formulation which is presented here is used.

2.2 THE DEMAND MODEL

The equation for the demand for ships of type i from yard j is assumed to be:

$$q_{ij} = d_{ij} \frac{P_{ij}}{\sum\limits_{\ell \neq j} P_{i\ell}/n-1} + e_{ij} \frac{\sum\limits_{\ell \neq j} P_{i\ell}/n-1}{P_{ij}} \tag{1}$$

Where n is the number of yards building ships of type i, and P_{ij} and q_{ij} are the price and quantity respectively of the type i ship in the j^{th} yard.

The parameters of equation (1) e_{ij} and d_{ij} are measures of the sensitivity of the quantity demanded from each yard to the relative prices of the yard. Since under the market structure assumed it is necessary to perform the analysis in terms of relative prices the d_{ij} and e_{ij} parameters are not easily expressed

in terms of price elasticities as they are conventionally defined. Because both of the price terms of equation (1) are functions of P_{ij} the elasticity of demand is a function of both d_{ij} and e_{ij}. However, if d_{ij} and e_{ij} can be determined it is possible to determine the response of the quantity demanded in each yard to a change in relative prices, which is precisely the objective of the demand model. Since the Navy is a price discriminating buyer the yard must consider the total number of offerers, not just the lowest cost producer, hence comparisons are made with market averages.

While theory predicts certain things about the parameters d_{ij} and e_{ij}, such as the fact that d_{ij} should be negative and e_{ij} should be positive, it is far from obvious that these parameters can in fact be determined. The purpose of the subsequent analysis is to establish a procedure for determining these parameters given the values of P_{ij} and q_{ij}. It is assumed that the Navy enters into the market to purchase a fixed number of ships (Q_i) to type i. This implies:

$$\sum_{j=1}^{n} q_{ij} = Q_i \qquad (2)$$

Since Q_i is fixed, its derivative with respect to any yard price is zero. If the right hand side of the equation (1) is substituted for each of the q_{ij}'s in equation (2) and the derivative with respect to, for example, P_{i1} is taken the following equation results:

$$\frac{-n-1}{\sum_{\ell \neq 1} P_{i\ell}/n-1} d_{i1} + \frac{n-1\ P_{i2}}{(\sum_{\ell \neq 2} P_{i\ell})^2} d_{i2} + \frac{n-1\ P_{i3}}{(\sum_{\ell \neq 3} P_{i\ell})^2} d_{i3} +$$

$$\ldots \frac{n-1\ P_{in}}{(\sum_{\ell \neq n} P_{i\ell})^2} d_{in} = -\frac{\sum_{\ell \neq 1} P_{ij}/n-1}{P_{i1}^2} e_{i1} + \frac{1}{n-1\ P_{i2}} e_{i2}$$

$$+ \frac{1}{n-1\ P_{i2}} e_{i3} + \ldots + \frac{1}{n-1\ P_{in}} e_{in} \qquad (3)$$

If this procedure is followed for each of the n prices for ships of type i the following matrix equation results:

$$\begin{bmatrix} \frac{-n-1}{\sum_{\ell \neq 1} P_{i\ell}} & \frac{(n-1)P_{i2}}{(\sum_{\ell \neq 2} P_{i\ell})^2} & \frac{(n-1)P_{i3}}{(\sum_{\ell \neq 3} P_{i\ell})^2} & \cdots & \frac{(n-1)\ P_{in}}{(\sum_{\ell \neq n} P_{i\ell})^2} \\ \frac{(n-1)\ P_{i1}}{(\sum_{\ell \neq 1} P_{i\ell})^2} & \frac{-n-1}{\sum_{\ell \neq 2} P_{i\ell}} & \frac{(n-1)P_{i3}}{(\sum_{\ell \neq 3} P_{i\ell})^2} & \cdots & \frac{n-1\ P_{in}}{(\sum_{\ell \neq n} P_{i\ell})^2} \\ \vdots & \frac{(n-1)\ P_{i2}}{(\sum_{\ell \neq 2} P_{i\ell})^2} & \frac{-n-1}{\sum_{\ell \neq 3} P_{i\ell}} & \ddots & \vdots \\ \frac{(n-1)\ P_{i1}}{(\sum_{\ell \neq 1} P_{i\ell})^2} & \vdots & \vdots & \ddots & \frac{-n-1}{(\sum_{\ell \neq n} P_{in})} \end{bmatrix} \underline{d}_i =$$

$$\begin{bmatrix} \dfrac{-n-1\ P_{i1}}{\sum\limits_{\ell \neq 1} P_{i\ell}} & \dfrac{1}{(n-1)P_{i2}} & \dfrac{1}{(n-1)P_{i3}} & \cdots & \dfrac{1}{(n-1)P_{in}} \\ \dfrac{1}{(n-1)P_{i1}} & \dfrac{-n-1}{\sum\limits_{\ell \neq 2} P_{i\ell}} & \dfrac{1}{(n-1)P_{i3}} & \cdots & \dfrac{1}{(n-1)\ P_{in}} \\ \vdots & \vdots & \dfrac{-n-1}{\sum\limits_{\ell \neq 3} P_{i\ell}} & \ddots & \\ \vdots & \vdots & & & \dfrac{-n-1}{\sum\limits_{\ell \neq n} P_{i\ell}} \end{bmatrix} \underline{e_i} \tag{4}$$

Note that these equations do not involve an assumption of maximizing behavior; they are the result of differentiating a term which is assumed to be constant.

Defining the matrix on the left hand side of equation (4) to be A and the matrix on the right to be B and solving for the d_{ij}'s in terms of the e_{ij}'s results in:

$$\underline{d_i} = A^{-1}\ B\ \underline{e_i} \tag{5}$$

Substituting this expression back into the n equations of the form of equation (1) yields:

$$
\underline{q}_i = \begin{bmatrix} \dfrac{P_{i1}}{\sum_{\ell \neq 1} P_{i\ell}/n-1} & 0 & 0 & \cdots & 0 \\ 0 & \dfrac{P_{i2}}{\sum_{\ell \neq 2} P_{i\ell}/n-1} & \ddots & & 0 \\ & & & \ddots & \vdots \\ 0 & & & & \dfrac{P_{in}}{\sum_{\ell \neq n} P_{i\ell}/n-1} \end{bmatrix} A^{-1}B\underline{e}_j + \begin{bmatrix} \dfrac{\sum P_{i\ell}/n-1}{P_n} & 0 & 0 & \cdots & 0 \\ & \ddots & & & \\ & & & \ddots & \\ 0 & & & & \dfrac{\sum_{\ell \neq n} P_{i\ell}/n-1}{P_{in}} \end{bmatrix} \underline{e}_j \qquad (6)
$$

Using equation 6 it is possible to solve for $\underline{e}_j$ in terms of the prices and quantities. Using equation (5) it is then possible to solve for $\underline{d}_j$. Using price data adjusted for delivery time the results of regressing an equation of the form of equation (1) agree very closely with the results obtained on the basis of the foregoing analysis. This agreement of a purely statistical approach and of the more theoretical approach taken here can be interpreted as an indication that the theory provides a reasonable representation of the price/quantity relationship.

Once a set of historical values for $\underline{d}_i$ and $\underline{e}_i$ are determined a regression against independent variables will be performed using these values as the dependent variable. These independent variables will be factors which can be of possible significance in the market. Some of the decision variables of the Navy will be included in the model in this fashion.

PRELIMINARY DEMAND MODEL RESULTS

- INITIAL ACQUISITION OF ONE SHIP FOLLOWING LEAD SHIP. DEMAND EQUATION FOR EACH YARD IS:

(7) BATH $q_1 = -0.03 \frac{P_1}{P_{AVij}} + 1.14 \frac{P_{AVij}}{P_1}$

(8) TODD SEATTLE $q_2 = 0.902 \frac{P_{AVij}}{P_2}$

(9) TODD S.P. $q_3 = -0.018 \frac{P_3}{P_{AVij}} + 1.016 \frac{P_{AVij}}{P_3}$

- 1978 ACQUISITION YIELDS 3 SHIPS IN EACH YARD (PRICES ADJUSTED FOR ESCALATION BASED ON DELIVERY DATE). DEMAND EQUATION IS:

(10) BATH $q_1 = -0.003 \frac{P_1}{P_{AVij}} + 3.803 \frac{P_{AVij}}{P_1}$

(11) TODD SEATTLE $q_2 = 3.024 \frac{P_{AVij}}{P_2}$

(12) TODD S.P. $q_3 = 0.009 \frac{P_3}{P_{AVij}} + 3.96 \frac{P_{AVij}}{P_3}$

Preliminary anlaysis, based on reported contracts awarded adjusted for inflation, yields the estimates of $\underline{e}_i$ and $\underline{d}_i$ presented in equations (7) through (12). These estimates indicate that the yards are at a position on the demand curve which is inelastic. However, the indication is that demand curves become more elastic over time. This increasing elasticity is quite possibly due to the competition which exists in the market. The hypothesis that competition is a relevant factor can be tested by using the number of yards in the market as one of the independent variables in the previously mentioned regression.

2.3 THE OPTIMIZATION ALGORITHM

For a given set of ships to be acquired under the necessary cost and market conditions the problem reduces to the determination of the optimal allocation of these ships among yards capable of producing them. This optimization is currently stated in terms of minimum cost by consensus of Navy authorities. Any other quantifiable goal can be used if it is deemed useful. Our problem here is to determine an algorithm to perform the optimization.

The optimization problem faced in this case has some unique characteristics that present problems for optimization algorithms. The most obvious of these characteristics is the lumpy goods nature of ships. The problem is integer in nature; it makes no sense to allocate fractions of ships. Therefore, the algorithm must not result in fractional distributions.

Another characteristic is that this optimization must be accomplished under a potentially large number of constraints, some of which cannot be specified in advance. This requires an algorithm which allows easy implementation and manipulation of constraints by the user.

The optimization algorithm which is presently being investigated is a combination of extended Lagrange multiplier and centroid techniques. The extended Lagrange multiplier technique is used to convert the constrained optimization problem into an unconstrained optimization problem. A centroid technique is then applied to solve the unconstrained problem. The extended Lagrange multiplier technique has the feature of easy constraint implementation. The centroid technique can be adjusted to select only points with integer values of ships.

It will be assumed for purposes of explanation that the Navy's goal is to minimize the total cost of acquiring the ships required to meet its desired fleet level. The object, therefore, is to minimize $\underline{P}.\underline{q}$ where $\underline{P}$ is the vector of prices paid and $\underline{q}$ is the vector of quantities of each ship type produced by each yard. There are of course constraints on this optimization. The prices and quantities must satisfy the objective functions and the demand functions for ships perceived by each yard. It follows that expressions to be minimized can be put in the following classical Lagrange multiplier form.

Minimize:

$$\underline{P}.\underline{q} + \Sigma\lambda_{1i} \text{ (objective functions)} + \Sigma\lambda_{2i} \text{ (demand functions)}$$

Since any reasonable objective functions must consider cost of production, the cost model must also be used in the optimization. The procedure is to arbitrarily select values of $\underline{\lambda}$ and then use the centroid technique to minimize the cost functions. By evaluating the constraints it is possible to determine whether to increase or decrease the values of λ. This process is repeated until the values of λ selected cause

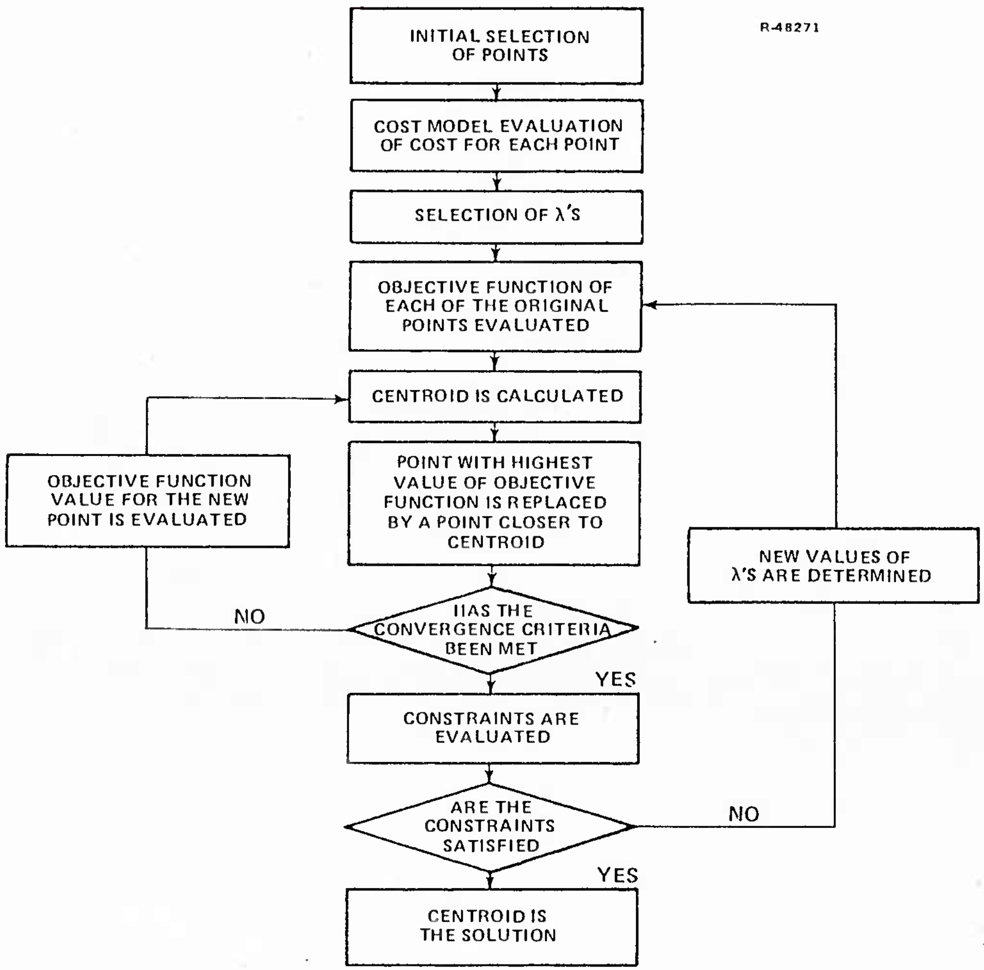
the constraints to be satisfied. A flow chart diagramming the above discussion is presented in Figure 2.3-1.

This method has several advantages. The first advantage is that the point eventually chosen will be in the area bounded by the set of initial points chosen. This means that if all of the starting points have a required property then the point which is eventually chosen will also have this property. For example, if all initial points have aircraft carriers produced only at Newport News, then the chosen point will also have this property. This is a particularly easy technique for implementing constraints. This eliminates problems associated with arrival at a mathematical solution which is not reasonable. This of course assumes that the initial points chosen are reasonable points. Techniques for choosing these points will be discussed later.

The second major advantage of this technique is that it allows the objective functions or the cost functions to be of arbitrary form. Theoretically the only restriction on these functions is that they be defined on a convex set. A convex set is one in which the line joining any two points is also in the set. In practice, however, even this limited assumption is hardly ever needed. The fact that only the value of the functions is used (as opposed to derivatives) means that the functions need not have derivates or even be continuous. An additional advantage of only using the value of the functions is the ease with which the technique can accomodate changes in the cost model or function to be minimized. This is potentially of considerable importance since to include additional constraints (such as one of only a selected number of yards getting the contract for a particular ship) one simply adds the constraint to the objective function (multiplied by an additional Lagrange Multiplier) and inserts the new constraint in the constraint evaluation block.

Figure 2.3-1

FLOW CHART OF THE OPTIMIZATION ALGORITHM



The choice of the original set of points from which the algorithm starts can be handled in a number of different ways. One reasonable approach would be to select an allocation and evaluate the costs for each yard. One then selects quantities and prices which are reasonable based on the costs to the yard. It is possible to select only a few points and then add random factors to these points to generate the remaining points.

The principal difficulty with this approach is that while the solution to the constrained optimization problem may exist, the solution to the unconstrained problem may not. In this case the centroid technique will converge on a point on the boundary of the area enclosed by the original point. It is possible that this may continue, and no point which satisfies the constraints is ever located. One resolves this mathematical difficulty by selecting monotonic functions of the constraints and functions to be minimized, in a manner which ensures the existence of a solution to the unconstrained problem.

This technique has been successfully applied to the present version of the planning model. Due, however, to the fact that the model as it presently exists is in the form of an interpretive computer language and it is eventually going to be in an assembled language, it is impossible at this time to estimate the computer time requirements to exercise the algorithm. It is not anticipated that solution times will be excessive.

2.4 DATA

Both the yard-specific and ship-specific data deemed necessary to the modeling effort in the Phase I feasibility determination are collected by, and accessible to, the Navy. Thus, data is not a constraint faced by the Navy in eventually using the fully developed model. The ship-specific data problem

experienced by TASC and solved in concert with ONR over the past year has been of a different type. The existence of the needed data was not the question; rather, the problem is one of TASC's access to data needed in the process of model development viewed as proprietary by shipbuilders. A partial solution to this problem (partial in that to date only FFG and DDS data are available via this route) developed in conjunction with ONR, NAVSEA and NAVWESA has been to provide TASC with "disguised" data from cost performance reports currently being computerized by NAVWESA. The data provided to TASC is sufficiently different from the actual data, so as to remove the proprietary objection, but still sufficiently reflects actual data so as to allow an orderly progression of model development. The first set of this data from the FFG program has been supplied to TASC. It is anticipated that a similar set of disguised DDS data will be made available to TASC by NAVWESA and the program office upon formal request by ONR and NAVSEA.

While the recent success in obtaining the data noted above has been helpful, an accessibility problem still exists where other shipbuilding programs are concerned. For instance, neither SSN 688 or Trident cost performance reports have been computerized by NAVWESA nor have program offices been solicited to devise alternative administrative means of providing data. Nevertheless, the precedent established in obtaining the disguised FFG data portends well for overcoming the accessibility problem where other ship-specific data is concerned. In the case where sole source production occurs (e.g., carriers) the proprietary obstacle may not be as substantial as in the FFG program where transmission of sensitive information between competitors is an issue.

Yard-specific data presents a different, and thus far, less difficult problem. Published sources provide a large part of the information required and the cooperation of individual

yards, and the Shipbuilders Council has allowed this data to be verified and supplemented by expert opinion (e.g., level of work force experience) garnered during extensive interviews with shipbuilders. It is our expectation that these vital interviews will continue during the remainder of Phase II of the effort.

In summary, the status of the data collection effort necessary for model development is:

- Both the yard specific and the ship specific data required exist and are available to the Navy
- TASC has recently received "disguised" ship specific data for the FFG program, and anticipates obtaining DDS data in the same form
- Problems remain in devising administrative procedures to obtain other necessary ship specific data to be used by TASC in its model development activities.

2.5 COST MODEL DEVELOPMENT

Parameters of the cost model were determined based on hypothesized conditions of a composite yard at five different times. A typical FFG-type yard was used as in Table 2.5-1. These hypothesized conditions allowed us to solve for the parameter values in the model. The procedure was implemented to permit preliminary checkout of the model because of difficulties encountered in timely receipt of actual data. The purpose of this exercise was to obtain a set of reasonable parameter values which could be used to determine the general appropriateness of the model's response to a varying set of conditions.

The results presented here assume that the lead ship of the class has already been constructed, i.e., ship #1 is actually the second ship of its class to be constructed. In

TABLE 2.5-1

BASELINE CONDITIONS

R-49951

- INFLATION RATES
  - GFE: 14 PERCENT
  - NON BUILDING PROCESS COSTS: 11 PERCENT
  - VENDED MATERIAL: 9 PERCENT
  - LABOR: 6 PERCENT
  - RAW MATERIALS: 9 PERCENT
- LEARNING FACTOR: 0.06 PERCENT
- WAGE RATE: 7.60 DOLLARS/HOUR
- ESTIMATE OF LABOR REQUIREMENTS: 3.5×10^6 HOURS/SHIP
- LABOR WINDOW: 4500 OPTIMUM EMPLOYMENT LEVEL
- PRODUCTION RATE: ONE/YEAR; LEAD SHIP PREVIOUSLY PROCURED

addition, the yard management is generally following a policy to maintain a fixed backlog. This is presumed to insure long-run efficiency. It should be recognized that these assumptions do not restrict the total model under development but are made to control the cost model. For the general model to be programmed in the next phase of this project a minimum cost construction policy within constrained delivery times will be used. This requires the coupling of the optimization model discussed in Section 2.3.

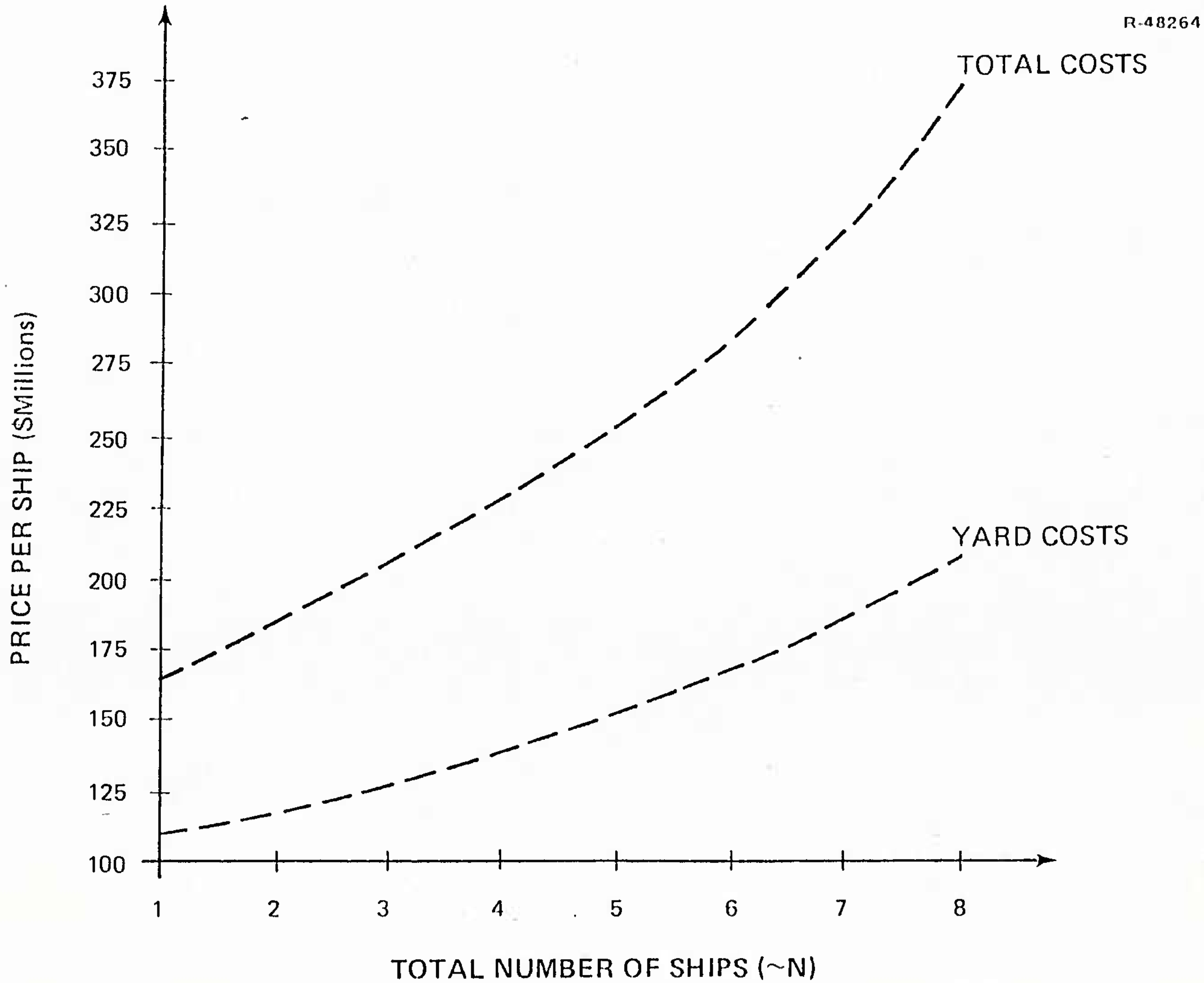
For conditions existing in the market at this time, the principle driving factors of cost are the various inflation rates and the learning phenomenon. In general, even a moderate inflation rate will eventually produce exponentially increasing costs overriding other factors, such as learning. Analysis with the model does, however, indicate that both learning and the ability to stay in the "labor window" can result in significant cost savings. The model also indicates that the estimated costs are extremely sensitive to the estimated labor requirements. This is a potentially significant result since it is this variable which has the highest potential for management by the yard, a phenomenon which was well demonstrated during our interviews.

Figure 2.5-1 illustrates the baseline case for this analysis. It shows both predominant effects, inflation and learning. Note that the gap between total costs and yard costs increases dramatically in this scenario. This is at least a preliminary indication that the most significant portion of the increase in ship costs at current inflation rates is not due to the yards, but it accounted for by subcontracted and GFE material.

To some extent this result is misleading since it is implicitly assumed that GFE acquired later is identical to GFE initially acquired. This is not generally the case.

Figure 2.5-1

BASELINE COST



- THE GAP BETWEEN YARD COSTS AND TOTAL COSTS GROWS RAPIDLY
- COSTS ARE INFLATION DRIVEN
- EVIDENCE OF A SIGNIFICANT GFE PROBLEM

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The exponential growth of both curves is of course the result of inflation. While it can be argued that it is real costs which should be considered the process of appropriations of funds is such that nominal sums may be the relevant variable. In either case the effects of differential inflation rates among the various components will impact relative long term cost for different acquisition strategies.

Figure 2.5-2 differs fundamentally from the other plots shown here. It is assumed that labor is adjusted optimally over the entire period. This assumes that the yard operates as if it will be allocated a ship each year for eight years, hires the required number of people to perform this task and maintains this level of employment throughout. It is interesting to note that the result of this smoothing of labor fluctuations is a very considerable savings in comparison with the case when a more myopic goal is assumed. This is an indication that considerable savings could be attained by simply stabilizing, in an operative manner, the Navy's demand for ships. Note that this Figure should be compared to Figure 2.5-3 since inflation is assumed to zero.

Figure 2.5-3 is a plot of total cost and yard cost if there is no inflation. The learning curve phenomenon accounts for the decline in cost between the first and sixth ship. After the sixth ship the yard is forced out of its "labor window" by an increasing backlog. This phenomena occurs because the addition of one new ship contract each year results in a slight increase in the size of the backlog since labor hours produced by the nominal employment level are not sufficient to build an entire ship in a single year. The backlog therefore grows a little each year. The increased backlog must eventually be compensated for by an increase in the labor force. This change in the labor force increases the number of man hours required to build a ship due to the fact that new labor is less efficient.

Figure 2.5-2

LEARNING WITHOUT INFLATION (OPTIMALLY ADJUSTED LABOR)

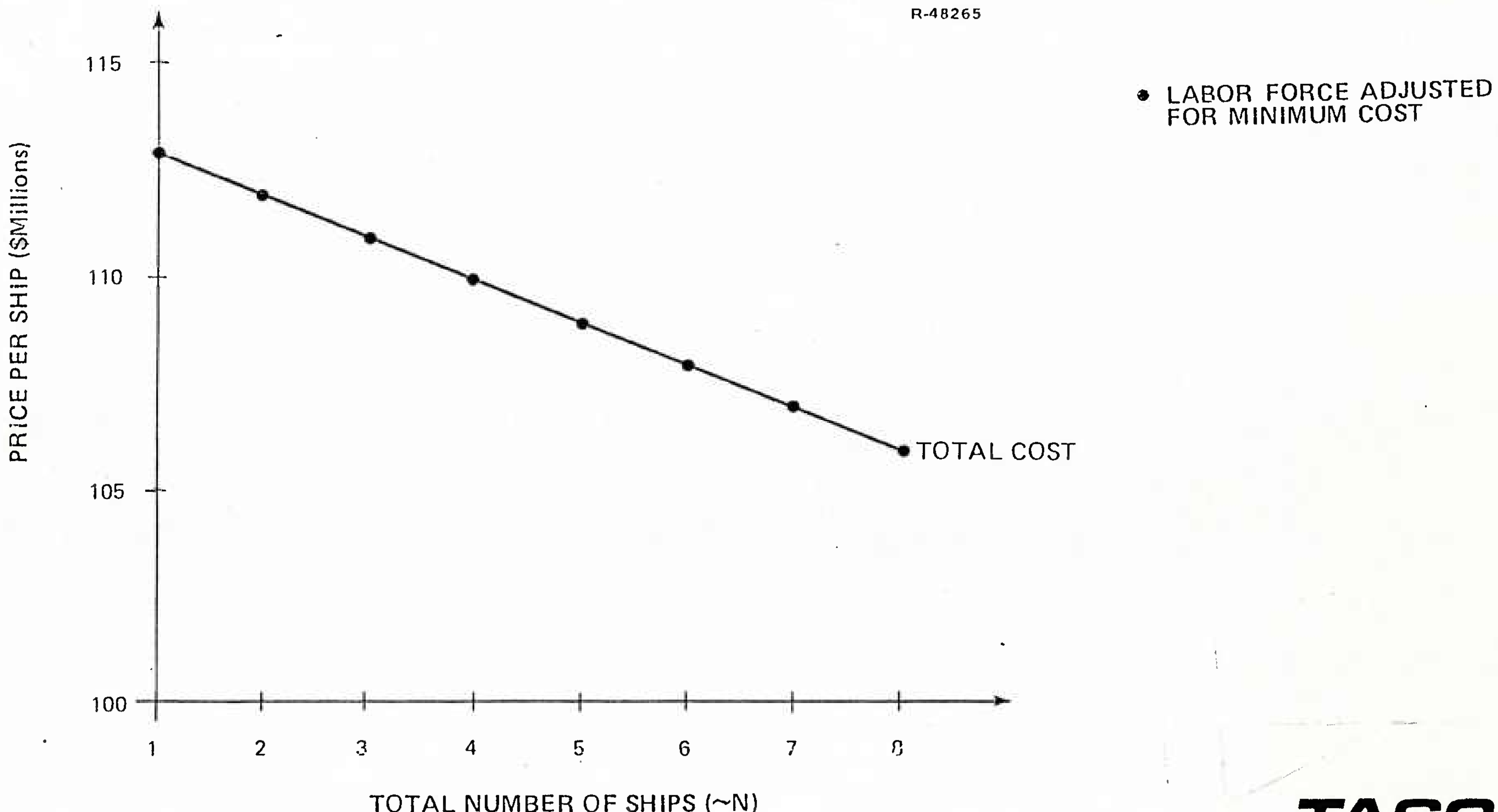

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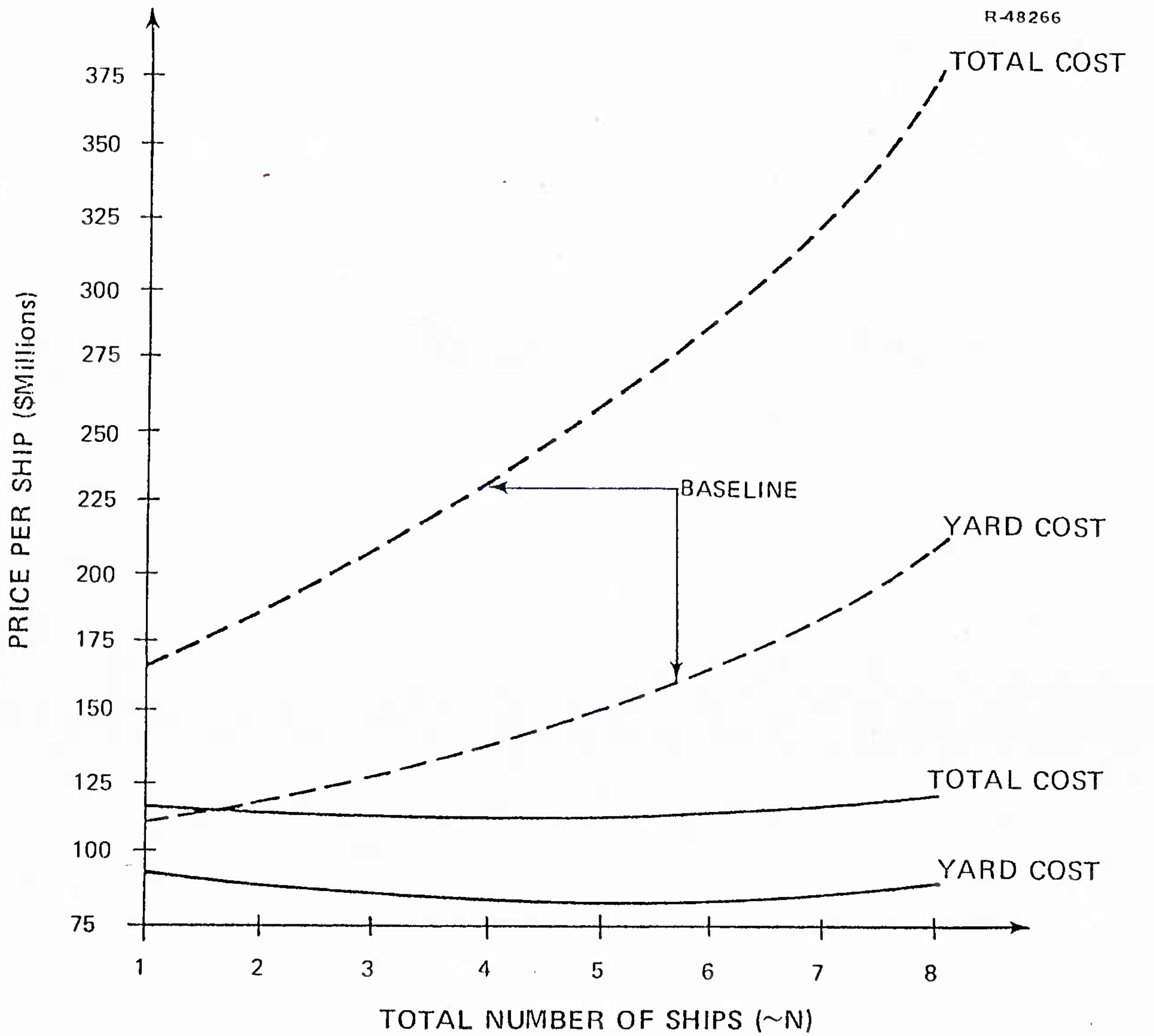
Figure 2.5-3

LEARNING BUT NO INFLATION



- YARD MAINTAINS FIXED BACKLOG
- LEARNING PRODUCES DECLINE IN SHIP COST FOR FIRST SIX SHIPS
- INCREASED COST AFTER SIXTH SHIP DUE TO LABOR INEFFICIENCY FROM INCREASED EMPLOYMENT

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Under the scenario of an additional ship contract each year this effect continues to grow, eventually causing the yard to move out of its labor window and the cost of the ship to increase. If this effect actually takes place this argues strongly that even in the absence of inflation the timing and quantity of contracts won by a yard must be carefully managed.

Figure 2.5-4 is simply a projection of total costs and yard costs if inflation is assumed to continue as at present and learning does not occur. These curves show costs growing exponentially as would be expected with yard costs increasing slightly due to the labor window effect.

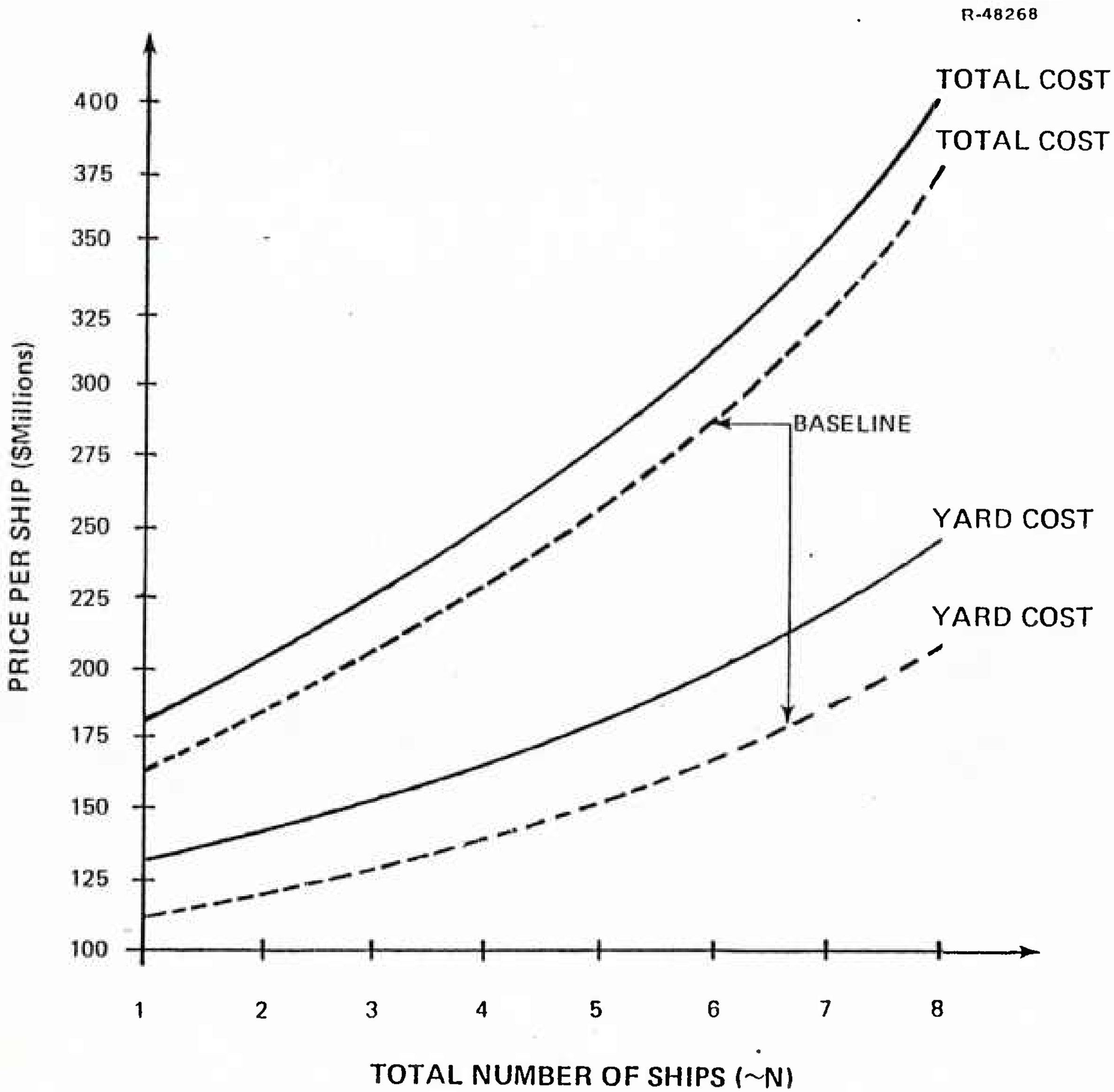
Figure 2.5-5 shows the effect of learning on yard costs. The initial cost difference between the two curves is due to the first ship being the first ship following the lead ship. The lead ship is not included in this analysis since its relatively high cost would dramatically distort the equation set. The lead ship will be handled as a distinct item from follow ships of the same type. The initial difference is therefore attributable to the fact that learning occured on the lead ship in one case and not in the other.

Notice that these plots indicate that learning results in approximately a $50 million savings after the sixth ship, but that this savings remains relatively constant. This is due to the fact that after a certain number of ships have been produced (in this case six) very little additional learning takes place, but the accrued advantage is maintained.

The sensitivity of the cost model to the number of labor hours required to build a ship is illustrated in Figure 2.5-6. In this case it is assumed that the yard, by its enhanced productivity, is able to reduce labor hours by 20 percent. The initial cost of the ship is adjusted primarily through

Figure 2.5-4

INFLATION WITHOUT LEARNING



- EXPONENTIAL GROWTH OF COSTS
- YARD COST INCREASE PARTLY DUE TO LABOR WINDOW EFFECT

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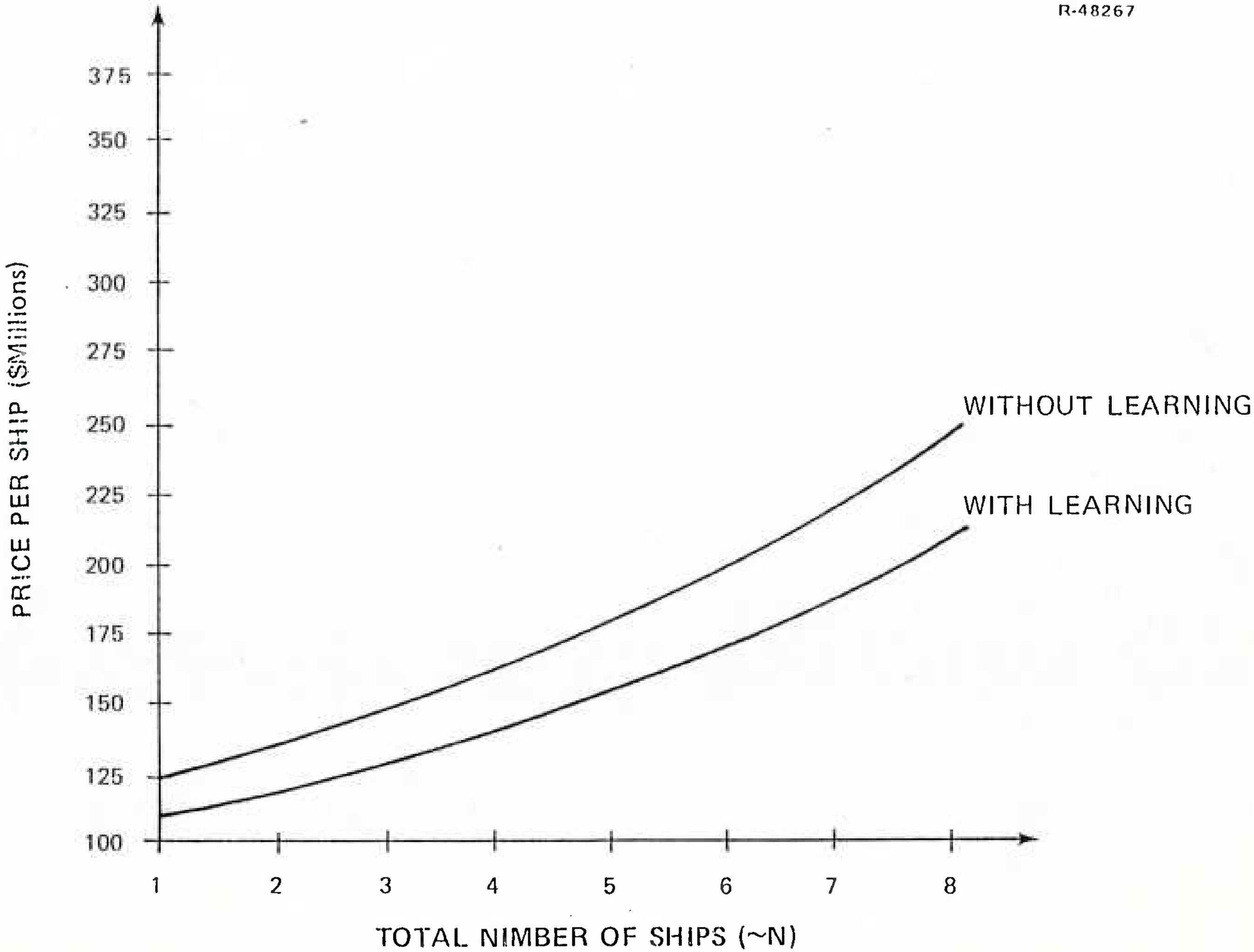
Figure 2.5-5

COMPARISON OF YARD COSTS WITH AND WITHOUT LEARNING



- THE LEARNING AFFECT IS SAVING APPROXIMATELY 50 MILLION DOLLARS BY THE 8TH SHIP
- THE CURVES ARE GROWING AT APPROXIMATELY THE SAME RATE BY THE 6TH SHIP
- INITIAL DIFFERENCE DUE TO THE LEAD SHIP COMING BEFORE SIMULATION

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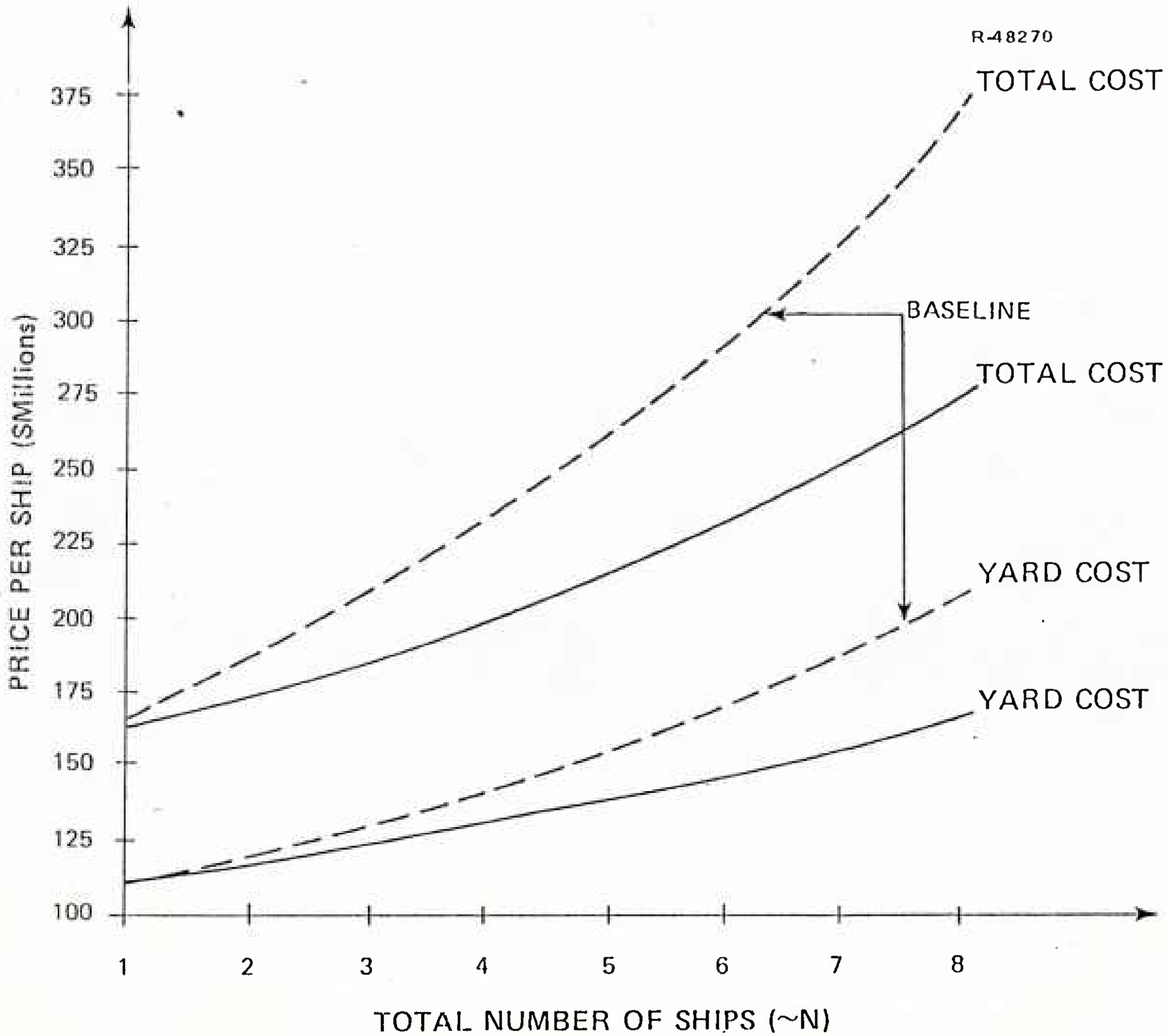
Figure 2.5-6

PRODUCTIVITY IMPROVEMENT WITH DECLINE IN WORK FORCE



- NAVSEA MANHOUR ESTIMATE REDUCED BY 20% LABOR/RATES INCREASED BY 20%
- COST SENSITIVE TO LABOR REQUIREMENT ESTIMATE
- BACKLOG HELD CONSTANT
- SAVINGS ARE PRIMARILY DUE TO EARLY DELIVERY AND ABILITY TO STAY WITHIN THE LABOR WINDOW

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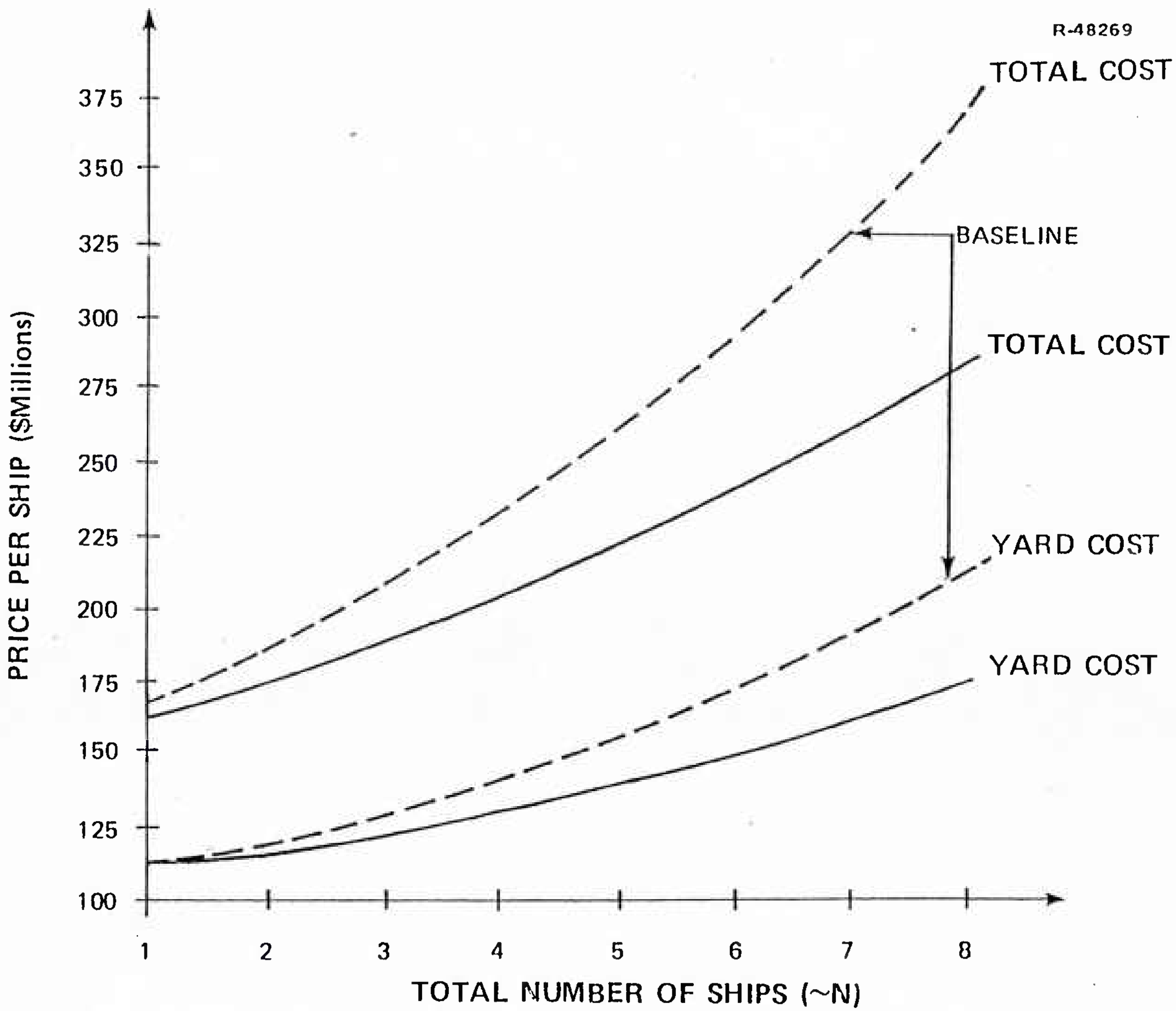
increasing the wage rate to correspond to the initial base line cost. Even after this adjustment the reduction in required labor hours results in very substantial savings. This savings is primarily due to earlier delivery dates and the ability to stay in the "labor window." That is, the yard is capable of producing a ship in a shorter time. Therefore, less inflation is experienced and the total cost of the ship is reduced. It should be noted that this may be a temporary phenomenon in that this situation results in a gradual decline in the employment level. If the final employment level is below the labor window, costs could be expected to rise due to the desire on the part of the yard to maintain a reasonable backlog and hence stretch out construction with an inherent inefficiency of labor use. This implies that increased efficiency of labor results in reduced costs of ships even if, for example, agreement is made with the labor force not to reduce total employment, Figure 2.5-7. To reiterate, this effect is due to the relatively early completion dates and the resultant reduction in inflationary impacts.

The principal conclusion of this sample analysis is that the model behavior concurs with intuition. The effects demonstrated by the model can be explained in terms of intuitively appealing arguments. This is a preliminary indication that the structure of the cost model accurately reflects the situation as it exists in the yard.

This section presents results on the effects of inflation rates, backlog, labor efficiency and long range planning. These results should be considered as indications of effects that the model could be used to illuminate. However, due to the nature of the coefficients used in this exercise, extreme care should be used in attempting to use the results obtained here for decision purposes. Since the coefficients were formed over estimated data it is entirely possible that some of these

Figure 2.5-7

PRODUCTIVITY IMPROVEMENT



- 20% LOWER LABOR REQUIREMENTS WITH CONSTANT LABOR FORCE
- SUBSTANTIAL SAVINGS RESULT DUE TO INFLATION AVOIDANCE
- LABOR RATE INCREASE BY 20%
- BACKLOG BEING WORKED OFF

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results will not be validated when actual data is used to estimate the model.

3. CHARACTERISTICS OF THE U.S. NAVY SHIPBUILDING MARKET

In this section we present an updated review of the shipbuilding industry, with particular reference to the policy-making role of the model. Its contents reflect the past year of effort incorporated into the advanced development of the cost component of the model, our ongoing review of current literature, and an extensive set of interviews with Navy and shipyard personnel involved in the FFG program.

3.1 U.S. SHIPBUILDING AS A DECLINING INDUSTRY

The dominant characteristic of the U.S. shipbuilding industry, impacting both commercial and Navy markets, is its prospect of medium-term decline. Due to both the industry's inability -- even with the government's subsidy program -- to meet the international challenges of the Japanese and, more recently, such developing countries as South Korea and Brazil, it is difficult to characterize the U.S. shipbuilding industry other than as an industry in decline. Standard indicators such as the relative profitability, low levels of investment, and slow growth of output are conventional indicators confirming this perception. Note that in the context of this declining industry, low profits, low investments and, perhaps most significantly, penetration of conglomerate ownership forms into the shipbuilding industry, some yards seek to maximize cash flow as opposed to profits.

The foremost implication of this situation for the U.S. Navy's demand for ships is the extreme dependence on Navy business for U.S. shipbuilders. Concomitantly, this situation

has implications for the U.S. Navy's long and short run goals with regard to the shipbuilding industry. It is impractical to presume that the Navy could look for much "support" from the commercial sector in obtaining either low costs in the short run (via either effective utilization of existing labor resources, or modernization of the capital stock) or for the longer term goal of maintaining the defense industrial base.

3.2 THE POLITICAL ELEMENT

Despite, or perhaps better expressed because of, its condition as a declining industry, shipbuilding is a relatively politicized industry. Two interrelated points account for the political nature of the shipbuilding industry. First, because it is a construction as opposed to a production industry* shipbuilding in the U.S. is a labor intensive industry. Second, for a variety of reasons, some of which are noted in the preceeding subsection, the U.S. industry is not competitive in the international commercial sector. This implies that the composition and level of demand for the U.S. industry's products, e.g., the Navy shipbuilding program, is, to a much greater degree than other industries, a matter of public choice. Therefore, the shipbuilding industry is intensively political -- with regard to its total budget size, type of ships constructed, and yards to which these ships are allocated. A most recent example of the political impact on the U.S. Navy shipbuilding market is a rider attached to the Defense Appropriations Bill, requiring the Navy to award a portion of the upcoming FFG flight to shipyards on each coast, regardless of cost considerations.

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*Frisch, Franz A.P., Production and Construction: A Comparison of Concepts in Shipbuilding and Other Industries, NAVSEA, Department of the Navy, Washington, D.C., July 1976.

The implication of the political nature of the shipbuilding market in the context of excess capacity is that an "efficient" or cost effective solution to the Navy's shipbuilding allocation problem is significantly constrained. These constraints are of two types: one, those resulting directly from the political process, largely arising from the perceived needs of legislators to maintain the favorable employment impacts of the existing shipyards for their constituencies. Two, the Navy's short run goal of cost effective shipbuilding at any single point in time may be in conflict with the longer run national security goal of maintaining an effective shipbuilding industrial base for mobilization capacity. With regard to this last point, it should be stated that preserving inefficient yards with old capital stock is questionable, at least on economic grounds, as an element in a strategy to preserve the shipbuilding industrial base.

Finally, it should also be noted that the description of the shipbuilding industry as "politicized" in this discussion should not be interpreted pejoratively. In an economy with imperfect market characteristics such as the U.S. economy, there is no reason to view employment <u>a priori</u> as a lower or less desirable goal than a cost-effective Navy shipbuilding program. However, when this choice is made, <u>we should be aware of its cost</u>, a piece of information which the model under development can provide. Making these costs clear and estimating their magnitude should prove helpful to the Navy by demonstrating to critics that not all of the costs, particularly cost overruns, encountered by recent Navy shipbuilding programs, are necessarily controllable by the Navy.

3.3 THE NAVY SHIPBUILDING MARKETS

At any point in time, with a given shipbuilding plan and budgetary outlay, it is inappropriate to classify the Navy's

demand for ships as a single market. Rather, shipbuilding, as far as the Navy is concerned, is characterized by a group of segmented markets depending upon the dominant characteristics of yards available to supply the Navy's demand (e.g. Newport News is the only yard presently capable of building a large conventional or nuclear-powered carrier) and to a lesser degree by the backlog of Navy business in any given yard. From the Navy's point of view at least two distinct but overlapping types of market situations exist in the short run. The first is one of assignment where given a single yard's capability to build a particular type of ship, the only effective short run means of cost control is tough negotiation and effective contract monitoring. The second is one in which the option of competition among several yards, in conjunction with negotiation and monitoring, can provide effective short run cost control. Our efforts thus far, using the FFG program as a test case, have focused on the latter situation. When fully developed, the planning model will allow the Navy to weigh the costs and benefits of providing a premium to any yard in order to introduce competition into a situation where assignment is the only current policy option.

3.4 FFG CASE STUDY

In the course of this year's effort we have focused our attention on the FFG program as a verification case for model development. Activities included literature review, interviews with shipyard and Navy personnel, and use of a "dummy" FFG data set to develop the model's cost and demand components. This focus is appropriate primarily because accessibility to the program has allowed model characteristics to be developed realistically. The program is multi-yard, multi-ship, competitive, and has a long time horizon, thus allowing the model's capability to be tested by these

difficult conceptual issues. The focus on the FFG has been reinforced by data availability (see Section 2.4).

The FFG market is currently driven by three factors:

- The relative efficiencies of the three yards involved
- The Navy's acquisition strategy emphasizing competition during the entire life of the program
- Politically-motivated allocation of ships to specific yards.

With regard to politically-motivated allocation two points should be made -- first, the model under development is capable of quantifying the cost to the Navy of such interventions; and second, in the context of the overall FFG program strategy of competition, it does not necessarily follow that financial repercussions must be large (see below).

The relative efficiencies, ultimately the productivity, of the three yards producing FFG's is determined by a mixture of management skill and decisions, investment, construction technology, and the stability and experience of each yard's labor force. Given that these relative efficiencies differ, why shouldn't the most efficient yard be granted, at least with reference to short run minimization of Navy costs, all of or at least a substantially larger portion of the ships to be produced? Two primary factors stand out -- the interaction between time, backlog and inflation and the preservation of cost saving associated with competition. The first point is essentially straightforward, given current inflation rates in excess of ten percent the cost differentials between yards quickly evaporate as a given yard is allocated a ship to be produced in the future. Thus, e.g., a $2.5 million differential per ship (as estimated by one interviewee) is quickly

compensated for by a year's worth of inflation when a contracted ship costs in excess of $60 million. It is worth noting that this conclusion is valid even in the face of a ten percent overrun by the relatively less efficient producer and/or an offer of a firm fixed price -- with escalation for inflation -- by the more efficient producers.

The second point relating to the role of competition is more complicated. Our perception of the FFG market, which is supported by the interviews and analysis undertaken during the past year, is one in which considerable gaming is undertaken by the competing yards with the most efficient yard having an option to practice a kind of limit pricing. The Navy's acquisition strategy in this context results in a hypothetical cost saving -- hypothetical in that it is only by recourse to theory and a counterfactual argument that such a claim can be made.

Limit pricing in an FFG type market can work as follows -- given the environment of competition established by the Navy, the most efficient producer takes account of the minimum price which its competitors can offer and remain viable, e.g., a price which produces the minimum benefit given a particular objective function acceptable to the less efficient producers. Knowing the minimum price of its competitors, the efficient firm can establish its own price taking account of the number of ships it wishes to produce. Thus, the presence of competing yards forces the efficient producer to limit its price by its competitors' offers. In the absence of a limiting presence it is not overly speculative to argue that the efficient producer could charge the Navy a higher price by expanding its cost base -- certainly a ten percent higher cost base in the absence of competing yards would be a distinct possibility.

An immediate caveat should be made: the awareness of all parties concerned -- the Navy and the yards -- of a political element in the allocation of FFG's effects the offers made by the shipbuilders and those accepted by the Navy. The effect of political intervention is probably to increase the cost to the Navy. The bids of relatively less efficient producers are probably higher than their limiting minimum would otherwise be, thus raising the entire array of offers made to the Navy. As mentioned before, however, total cost to the Navy is not alwasy the only public policy issue.

Our interviews with Navy and shipyard personnel confirmed much of the above argument. All of the yards were aware of the others' costs and current situation, not only through public information but also via continuing technical consultation. Thus, an information base upon which competitors' offers could be calculated was present. Yet, as recent developments indicate, a gaming result is by no means perfectly predictable. Assuming that the competing firms did not game optimally in the last buy, a reward to the Navy could well be reaped in the next round of competition if the government does not interfere with the natural evolution of this market through political intervention.

The above represent our general findings on the market behavior of the FFG program. With the recent acquisition of a "disguised," near-complete FFG data set*, the next year's effort will include further analysis of the issues raised above as part of the overall model development, and, undoubtedly, new issues will emerge. In addition to the dynamics of the FFG marketplace our examination of the program illuminated a

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*The FFG data set only lacks bid information.

number of additional insights concerning the shipbuilding process.

A major premise of the above argument is the relative efficiency among yards. While this phenomenon is broadly accepted, an examination of the factors which account for relative efficiency is appropriate. These factors, are interrelated, and if adequate capacity utilization is maintained, self-perpetuating. They support the rationale justifying the initiation of this model development project in its first instance because the Navy will have a mechanism to control this behavior in as much as the market permits.

The productivity of the labor force is certainly a foremost factor. The provision of adequate work throughout the 1970's has given a competitive advantage to those yards with a stable and experienced labor force, particularly in the skilled occupational classifications. If this shows in the marketplace, it will be predicted by our modeling equations. In turn the strength of the labor force can be enhanced by both internal investment programs designed to increase productivity and adequate in-house planning. Our interviews verified this conclusion.

With regard to investment behavior and contract performance it can be speculated that the relative efficiences of the yards at any given point in time can be associated with differing corporate strategies, addressed in the model by different objective functions and historical efficiency. A financially health shipyard might optimize its return on assets, consistent with both its level and type of investment. Those yards in more precarious financial positions, as per our interpretation of interview results, might have the different corporate objective of maximizing cash flow rather than profits or return on assets. A firm with a cash flow objective

will attempt "front end" loading in order to increase its volume of cash in any given period. This strategy is viable if learning is substantial enough to allow later paybacks. But accordingly the risk associated with overruns is increased on the last ships built. In the long term a cash flow maximizer will disinvest due to failure to replace depreciating assets, thereby increasing cost in the future. This will have an impact during the term of the planning horizon contained in our model.

4. BACKGROUND ANALYSES

4.1 GOVERNMENT FURNISHED EQUIPMENT

The examination of the issue of government furnished equipment (GFE) was initially undertaken as a necessary part of the model development activities. Specifically, GFE is included in the model's cost component directly (with adjustment for inflation) and indirectly as one of several factors impacting cost through schedule slippage (thus increasing cost not only by inflation upon the GFE component but also stretching out the period of time during which other components of cost are subject to inflationary pressures). For the model's primary task -- providing the Navy with a tool to allocate ships among the yards comprising the industrial base -- the above response gives sufficient consideration to GFE's role in the shipbuilding costs.

However, from the literature reviewed, our interviews with Navy and shipyard personnel, and the results of our exercise of the yard cost component of the larger models, it has become evident that GFE is a major factor in the total cost to the Navy of any ship acquired, and thus deserves more attention. For example, in the Baseline Cost Estimate (see 2.4 for a description of the relation between the hypothetical data set and actual FFG costs) yard costs as contracted account for only about two thirds of the total cost to the Navy of the second ship produced. By the eighth ship, the fraction accounted for by yard cost has fallen to about one half, responding to the higher rate of inflation prevalent for GFE. The bulk of the remaining cost after allowance for escalation must certainly

be accounted for by GFE. This result, by itself, is not surprising, because the GFE component includes high technology goods such as complex navigation and guidance equipment and weapon systems. What is surprising is the lack of systematic data and analysis to shed light on this large component of shipbuilding cost.

The problem of cost control reduces to first, understanding if the GFE component has grown as a proportion of shipbuilding costs and second, identifying the elements determining the level of GFE cost -- the aforementioned high technology element, small orders, sole source producers, lack of coordination between program offices, etc. Application of acquisition research experience might, if more generally applied, lower GFE costs. At the present time no aggregated data set exists to address the larger problem, but our own and others' examination of the FFG program revealed acquisitions strategies which may help to control GFE cost.

From our interviews and published sources several techniques by which the FFG program has managed GFE acquisition have intuitive appeal.* First GFE as well as other costs have been held down by the design approach to the FFG acquisition, namely accomplishing lead ship construction including finished detailed ship plans well ahead of the follow ship. Second, the strategy allowed Bath -- the lead ship contractor -- to purchase 31 sets of standard option equipment and to centrally procure GFE, probably resulting in savings via both bulk purchases and by providing adequate lead time to insure against increased cost due to schedule slippage. Third, in one case at least, cooperation among the shipbuilders and the program office allowed a set

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*Beecher, J.D. and A.R. DiTrapani, "The FFG Guided Missile Frigate Program -- Model for the Future," Naval Engineers Journal, June 1978, pp. 93-105.

of standard equipment to be swapped between builders preserving on time delivery and presumably accomplishing a "shadow" cost savings because schedule slippage was avoided. As a result of these and other sound acquisition policies GFE was perceived by the interviewed shipbuilders as an area where few problems had emerged.

The FFG program's acquisition strategy also illustrates the complexity of the GFE problem. Minimizing GFE cost per unit at each point in time by an extremely competitive strategy may not necessarily lead to minimum ship and program cost. In the FFG program a strategy was developed that emphasized standardization and cost savings resulting from large procurements by allowing Bath to act as the Navy's agent for gas turbines, diesel generator sets and main reduction gears for all of the FFG's built. This strategy sacrificed ongoing competitive procurement as program officials note, although the sole source for each item was determined in an initially competitive process. However, in theory it availed the FFG program to potential cost savings arising from:

- Standardization
- Adequate lead times to minimize the possibility of GFE late delivery impacting program cost via schedule slippage
- Economies of large scale production runs.

While the FFG program features give guidance for controlling GFE cost, its experience is applicable only to similar programs -- many ships built in a relatively short period of time -- and, even in this case, unknown effects concerning GFE cost growth are probably more significant than the recognized interventions (a point emphasized by one of the interviewed shipbuilders). The key policy question is, should GFE be a specific target for acquisition policy improvement? On the

other hand, have recent GFE cost increases been the result of the Navy's requirement for better and/or more complex equipment? Or has Navy procurement policy created a disadvantageous situation for itself in the marketplace by evolving long term sole source relationships with suppliers?

The absolute cost of GFE compared to the hull is significant enough to merit more extensive study. If addressable policy issues are identified the development of new policy approaches and tools would be in order. The results of such an effort could, at the proper time, be incorporated into the planning support model being developed under this contract.

4.2 ACQUISITION STRATEGY, PROCUREMENT, AND CONTRACT FORM

The contractual arrangements between the Navy and private shipbuilders can have a significant influence upon contractor cost and performance. Contract form and provisions are a part of the Navy's broader acquisitions strategy and thus, cannot be meaningfully discussed without consideration of these other parts of the Navy's strategy, particularly competition and the effective monitoring of contractor cost and performance. Our review of recent literature and interviews with Navy and private contractor personnel leads us to de-emphasize some traditional contractor motivation issues -- such as the efficacy of incentive contracts vs. straight cost plus fixed fee -- while directing emphasis toward issues such as risk sharing provisions, design stability and the transfer of designs between contractors in a competitive environment, and contract provisions relating to design changes during construction.

4.2.1 Cost and Contract Form

The major conclusion of our review of the traditional cost and contract form issue is that the form of a contract --

firm fixed price, cost plus fixed fee, or a variety of incentive types -- is not a substitute for a well-planned and implemented ship and systems acquisition strategy or accurate cost estimation. Furthermore, and not surprisingly, we find contract form to be a variable that must be examined in light of the particulars of the yard, industry and program situation.

Each of the major contract forms has its strengths and weaknesses which may be appropriate for different acquisitions situations or phases of a particular program. Firm fixed price contracts are best suited for a low risk standard item situation -- for example the purchase of off-the-shelf equipment or raw materials. Since this type of situation represents only a small part of ship and ship systems acquisition costs, firm fixed price contractual arrangements are not a major concern. As the technical risk associated with an item increases or the length of construction time, either the cost plus fixed fee or incentive type contract is appropriate. Empirical studies have shown that using cost, performance and schedule slippage criteria the apparent theoretical superiority of incentive type contracts relative to cost plus fixed fee contracts is not evidenced for a broad spectrum of DOD programs.* A caveat with regard to shipbuilding and the current state of excess capacity in the industry is that, should the industry (or an individual yard) operate at near capacity, delivery incentives may play an important role in assuring that Navy business (or subsets of Navy business) receives priority attention.

Cost estimation in large part explains the disparity between the expected savings of incentive contracts and the actual aggregate savings. In the incentive contract situation

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*Hiller, John R. and Robert D. Tollison, "Incentive vs. Cost-Plus Contracts in Defense Procurement," Journal of Industrial Economics, March 1978, pp. 239-248.

it is to the contractor's advantage to inflate the initial cost estimate, increasing the probability of incentive payments and correspondingly decreasing the probability of overruns and decreased profits. This is true even in a competitive procurement situation. Thus, while contractual formal overruns may be minimized through incentive contracts, Navy costs may not be. Superior technical performance is also a claimed advantage of the incentive form. However, broad surveys of the defense industry base lead to the conclusion that such incentives may be redundant in that contractors already place emphasis on meeting performance goals.

The FFG program illustrates an important consideration in the area of contract form. Contract form must be tailored not only to the particulars of a given program and ship type, but also to the particular phase of a given program. In the design phase of the FFG program and for the lead ship construction, a cost plus fixed fee form was used. For the construction of the follow ships cost plus incentive fee contract forms are being utilized. One ship builder has suggested that, given that his and the other yards have moved down the learning curve, fixed price with escalation contracts should be used for the remaining ships. The progress of forms is logical and reflects the decrease in uncertainty as more ships of a particular class are built, as well as the changing relative importance of various Navy objectives over the life of the program. For the design phase and lead ship construction, considering the large number of FFG's to be produced, quality was emphasized above cost, hence, the cost plus fixed fee contract. For follow ship construction, since a sound design requiring minimal changes results from the lead ship effort, cost and meeting delivery schedules (also indirectly impacting cost by controlling exposure to inflation) are emphasized by the cost plus incentive fee arrangement. The suggestion of a move to firm fixed price is logical when the program's progression thus

far is considered because the time necessary to build an FFG and the production process itself are, relative to the early days of the program, well known.

An issue in the FFG acquisition which is related to contract form is that of contract changes. An acquisition goal of the program was to minimize change orders, particularly unilateral ones, because of their obvious impact on costs. Several features of the program have served this objective, including the co-participation of Todd and Bath in the design phase, the lag between the lead and follow ships, bulk purchases of standard equipment, and ongoing technical consultation among producing yards.

4.2.2 Risk Sharing Provisions and Escalation Clauses

Profitability is a critical issue for private yards building Navy ships. U.S. shipbuilders are currently faced with low profits and a declining total demand for their output. The implication of this situation for U.S. national security is serious. Not only are the number of capable yards declining, but yards staying in business have adjusted downward their new investment to levels commensurate with declining profits and demand. In this context risk sharing and escalation clauses between the Navy and the contractor assume more than their usual importance. If the burdens of risk and inflation are shifted too much upon the contractor and thus create further downward pressure on the industry's profit, short run savings accruing to the Navy may be swamped by the higher cost of fewer builders in the future and a further diminution of the shipbuilding industrial base.

The construction of large Naval ships is an inherently risky situation, given technological complexity and long construction times, even in "normal" economic periods of price

stability. The rapid increase in inflation during the 1970's has heightened these risks. This increased risk and low profitability punctuate the need for a fair distribution of risk between contractors and the Navy.

In principle the shipbuilder should be held responsible for those elements under his control (e.g., meeting schedules as contracted), while the Navy should bear the burden of exceptional risk (e.g., high technology innovations) and those risks beyond the control of the shipbuilder (and in some cases the Navy) e.g., inflation. However, in practice these distinctions may be difficult to make, for example the determination of whether or not a shipbuilder pursues with adequate vigor wage negotiations where increased costs can be passed along to the Navy.

4.3 REPAIR AND CONVERSION AND COMMERCIAL CONSTRUCTION

Early in our modeling effort we concluded that the oligopolistic nature of the shipbuilding industry dictated that the model must be specific to each yard engaged in Navy construction. Since our modeling approach is based on yard level aggregation we must account for all shipbuilding activity taking place in the yard, i.e., Navy construction and other activity. Different solutions are used at present depending on the nature of each activity. Most of this extra activity is due to commercial shipbuilding and repair and conversion.

The procedure which is considered most appropriate at this time is to assume that repair and conversion work could be treated as a filler (an hypothesis confirmed in the interviews). That is, a yard attempts to get repair and conversion work in order to keep its labor force occupied when new construction does not suffice. Therefore, the amount of repair and conversion work which is sought and accepted is an inverse function of the

number of new ships which are going to be constructed in a given yard.

The method for treating the commercial shipbuilding industry is to predict when commercial ships will be constructed. This is to be based on analysis performed by MARAD. For Navy planning purposes, we can accept these estimates as valid, and treat them as backlog in the appropriate yards.

There are, of course, a large number of variables which can be used to predict the need for repair and conversion. For example, the periodic requirement for inspection will in general produce a periodic requirement for repair and conversion; since it is likely that only in conjunction with inspection will repair and conversion work be performed. Due to the fact that repair and conversion is treated as filler, and that the analysis presented here is preliminary in nature, we feel it would be unreasonable to attempt to comprehensively investigate the possible factors which contribute to predicting repair and conversion as a function of only time. With time as the only independent variable in the regression, we proceeded to specify the model for best statistical performance. As was previously noted, there is considerable reason to believe that there is cyclical behavior, and in point of fact the best statistical performance is:

$$y = 9239.9 - 2900.8 \left[\sin\left(\frac{2\pi}{30} t\right)\right] \tag{1}$$

where

y = man hours of repair and conversion work

t = years

This regression was performed over the period 1959 to 1978, and is the prediction of the total amount of reapir and conversion

work which will be available to all shipyards at a given time. The thirty year period probably reflects the after effects of post-World War II production. This of course does not solve the problem of distribution of this work. The distribution problem would be handled on the basis of the aforementioned rule of using repair and conversion as filler. That is, if a yard is very short of construction work, they will attempt to obtain a larger percentage of the available repair and conversion work. Equation (1) would be used as the maximum amount of repair and conversion which would be available to the industry, and therefore represents an upper bound on the amount of filler available to yards. Clearly this approach is subject to considerable improvement, and a more desirable procedure would be to establish causality between repair and conversion and other factors. Depending on the sensitivity of our model's results to the level of repair and conversion, it may become necessary to treat repair and conversion as a distinct job which is contracted in the same way as new construction but with a much shorter time frame. The proper technique will be determined on the basis of experience gained from exercising the model in order to determine the sensitivity to the specification of repair and conversion work.

Another reason for wishing to specify repair and conversion in a more causal fashion is that the explanatory power of the model is greatly increased if this variable can be modeled as a causal function of other variables, rather than as an exogenous variable which is simply introduced into the model without explanation. It is clear from even a preliminary analysis that there exists a causal relationship between the age of ships and the amount of repair and conversion required. Despite these caveats, the equation presented here tracks the actual output of repair and conversion fairly closely, and there is, therefore, reason to believe that this particular specification may be adequate for our purposes. Future effort in this area will

include more accurate modeling of the repair and conversion market as well as the demand for repair and conversion.

Further work is also necessary with regard to modeling the civilian ship construction work. A more sophisticated analysis of this segment of the industry is required in order to accurately predict its impact on military construction as well as to aid the civilian sector itself. It is anticipated that MARAD will choose to support this activity.

5. SUMMARY STATUS

At this time TASC is in a position to begin full scale computer program development. During Phase I of the Project, an approach was devised which was basically feasible. The approach at that time had several features which were deemed important to model the ship acquisition process in a manner which is likely to improve the ability of the Navy to plan and implement its shipbuilding program. These features included:

- Modeling the industry aggregates through predictions of individual yard behavior
- Cost predictions done on a yard comparison basis
- Recognition of the gaming nature of the oligopolistic industry
- Optimizing for long term minimum cost to the Navy
- Prediction of interesting aggregate variables such as employment and total cost
- Structure the positive aspects of appropriately managed competition.

These attributes of our approach to planning for shipbuilding have been preserved as the methodology has evolved over this year.

Our technical research activity this year has proceeded in three broad classifications: (1) further investigations of significant areas potentially affecting the model formulation,

(2) refinement of the equation set and solution methodology, and (3) preliminary data gathering activities. Progress has proceeded satisfactorily in all three areas. No obstacle has arisen which threatens the viability of our modeling approach or has raised questions which remain unresolved at this time.

As a summary statement of our findings in related areas we would like to point out some areas deserving research attention which are outside the terms of this study. GFE has been identified as a large and growing cost element of total ship construction. While we model GFE cost as a fixed cost with its own inflation rate a better simulation will require an understanding of the nature of GFE cost that is not available at this time. More research is recommended.

We currently treat the commercial market as an input quantity and as part of the yard's backlog. The commercial market could be treated internally in the model in a manner analogous to the Navy market. A proposal to incorporate such an approach is currently under evaluation by ONR. A similar finding is appropriate to the repair and conversion market. We plan to handle this component as a leveling mechanism after new ship construction has been assigned. This component is also subject to analysis of the market if further experience shows this has a significant impact.

Further analysis of the nature of the current shipbuilding market, including use of the FFG as a test case for analysis and interviews, validated our current modeling approach. As the data base is expanded to more yards and ship classes, a similar validation process should be used. We consider it vitally important to expend significant effort on validation activity to insure the continued reality of the model. An investigation of the Navy ship procurement process revealed

no instances which would limit application of the model as originally envisioned.

The equation set and solution methods were further refined. The window effect is now modeled as a parabola. This both suits the conceptual model of yard managements and is easier to handle analytically when compared to the piecewise linear form originally conceived. The demand equation faced by the yard has been changed to reflect the yard perspective more realistically and is better suited to apply the known data on bids received. Finally, an extended Lagrange multiplier technique has been tested as an optimization technique. This is conceptually sounder and computationally simpler than the heuristic approach suggested last year. All these approaches have been tested with simple programs prepared for a small computer. It is now appropriate to initiate full scale computer program development.

Recovery of the data needed to establish the yard parameters presented some difficulties through the year. The existance in Navy files of the appropriate data was easily established for the FFG program. We believe this will be available for all Navy construction. Problems arose concerning the proprietary nature of the data and the work required to recover the data. For the purposes of model development the data was disguised slightly to preserve proprietary interests. Recovery will take time but involves no conceptual difficulties. Recovery will become increasingly easier as Navy reporting requirements become more standardized and computer storage is used. No new data collection by the Navy will be required.

In summary we believe we have our outstanding problems well in hand and are poised for full-scale computer program development.

APPENDIX A

SHIP COST MODEL

from TASC TR-1337
PLANNING FOR NAVY SHIP ACQUISITION
December 1978

7.1 MODELING THE COST OF SHIPS

7.1.1 Introduction

The following approach develops quantitative relationships which determine the price of ships. Pricing is modeled in a two-stage process, wherein an estimate is first made of the cost to a given shipyard for building a ship, and this cost is then used in a separate module to estimate the price which will be acceptable to that yard for the ship. This second stage involves game theoretic considerations and as such is of a different nature from the first stage, which is a direct cost estimation.

The functional relationships between variables are tentatively formulated and are expected to change, based on later analysis with real data. Certain parameters given in the model are to be evaluated by a statistical package (PARAIDE) designed to permit testing of alternative functional representations to achieve the maximum likelihood fit to the data base.

The overall cost for a ship will be represented as the sum of costs, to the Navy and the shipbuilders.

$$C_{ij} = D_{ij} + O_{ij} + P_{ij} + G_j + U_j \qquad (7.1\text{-}1)$$

where:

C_{ij} = total cost to the purchaser of building j ship in yard i, in terms of dollars as expended (not constant dollars). This figure may include "cost overruns"

D_{ij} = direct cost to yard i of building ship j, in terms of dollars as expended

O_{ij} = overhead of yard i attributed to building ship of type j

P_{ij} = actual profit or fee accruing to yard i, in dollars, in the manufacture of ship of type j

G_j = cost of operational equipment furnished by purchaser (GFE, when purchaser is government)

U_j = costs to purchaser not directly related to building process (administrative, testing, etc.)

G_j and U_j will be taken as given quantities, for the present year. The only expressions concerning their values are:

$$G_j = G_j^o(1+I_g)^{t_1} \tag{7.1-2}$$

$$U_j = U_j^o(1+I_u)^{t_2} \tag{7.1-3}$$

where:

G_j^o = estimate of G_j if built at the present time

U_j^o = estimate of U_j^o if done at the present time

$I_{g,u}$ = inflation rate of this cost category

$\{t_k\}$ = times at which costs are actually incurred

Provision is made in the model for differential inflation rates. The best available inflation rate will be used for each cost component.

P_j will, of course, be dependent on the price stipulations in the contract between purchaser and builder. It is estimated in the second module.

D_{ij} and O_{ij} are dependent on yard operation and may be related to the conditions within a given yard, as applied to the ship under consideration. These relations are now developed.

7.1.2 Relations for D_{ij} and O_{ij}

Consider first the overhead O_{ij}, which is easier to formulate. We will express this as

$$O_{ij} = \dot{O}_{ij} D_{ij} + F_{ij} \tag{7.1-4}$$

where:

$\dot{O}_{ij}$ = overhead rate for yard i at the time of building ship of type j

F_{ij} = exceptional fixed investment, if any, for ship of type j by yard i

F_{ij} represents any fixed investment which must be made in yard i when a ship of type j is to be built there for the first time. This cost is allocated completely to the first ship rather than being spread over several ships of the same type. If the ship is to be built early in a plan period, the fixed investment will probably be written off over the plan period. If the ship is to be built later, then this costing procedure may cause an overestimation (if, in fact, more ships of type j are to be built <u>after</u> the five-year period) but it is anticipated that this error will be self-correcting by changes in later yearly replanning allocations.

We may write

$$F_{ij} = F^{o}_{ij}(1+I_f)^t \tag{7.1-5}$$

where:

F^{o}_{ij} = estimate of F_{ij} in the present year for yard i and ship j

I_f = inflation rate for capital investments

t = projected time at which special equipment will be expensed

The equation for overhead rate $\dot{O}_{ij}$ will be based on historial observation of its relation to yard conditions and is given as

$$\dot{O}_{ij} = \alpha_{1i} + \alpha_{2i}B_i + \alpha_{3i}\left(\frac{R_{ij}}{R_{ij} + V_{ij} + L_{ij}}\right)$$

$$+ \alpha_{4i}\left(\frac{V_{ij}}{R_{ij} + V_{ij} + L_{ij}}\right) + \alpha_{5i}\ S_i \qquad (7.1\text{-}6)$$

where:

B_{ij} = backlog of yard i at the time when ship j is being constructed, not yet completed but under contract

R_{ij} = initial estimate of present cost of material supplied by shipyard i for ship j

V_{ij} = initial estimate of present cost of subcontracts which will be procured by yard i to build ship j

L_{ij} = initial estimate of present cost of labor to yard i for ship j. (This is further described below)

S_i = average number of shifts operating per day. at yard i during period of building ship j

$\{\alpha_{ni}\}$ = parameters, to be determined

The direct cost D_{ij} is found from R_{ij}, V_{ij}, and L_{ij}, and is dependent on the time at which the ship is built and the experience with building type j ships:

$$D_{ij} = [L_{ij}(1+I_L)^t + R_{ij}(1+I_R)^t + V_{ij}(1+I_V)^t]\ (1+N_{ij})^{-\lambda_i} \tag{7.1-7}$$

where:

I_L = labor inflation rate

I_R = material inflation rate

I_V = subcontract inflation rate

t = time at which ship is built

N_{ij} = number of ships of type j previously built at yard i

λ_i = learning curve coefficient for yard i (with $\lambda_i>0$ to be determined from the data analysis)

Note that we have ignored the time elapsed between building the previous ships of type j at yard i. One might specify a cut-off point at which time previous experience is no longer considered valid. Also, it is clear that this formula would not hold for large values of N_{ij} (since $N_{ij}^{-\lambda_i} \rightarrow 0$ as N_{ij} increases), but the fit is expected to be good for the smaller N_{ij}'s associated with ships. This will not give the usual learning curve values since several of the effects normally attributed to learning are specifically included in our direct cost equation. Rather it will be a yard specific value based on the cumulative data base from the specific yard.

The estimated split of cost among labor, material, and subcontracts would be based on historical data for the given yard with regard to the type of ship under consideration.

A distinction is made between raw material and subcontracts since practice varies among yards.

One way to estimate direct cost is to use the NAVSEA method, where the components of the ship and its design are classified according to subsystem as hull, propulsion, electric, command and surveillance, auxiliary, outfit/furnishings, armament integration/engineering, and ship assembly and support services. Manhours and material associated with each subsystem are estimated by using standard multiplicative factors in connection with the estimated weight of each of the physical systems. This is then allocated to main contract work and subcontracts for a given yard by means of allocation factors, as follows:

$$H^{o}_{ij} = \sum_{k=1}^{9} W_{jk} h_{jk} f_{ik}$$

$$H^{1}_{ijk} = W_{jk} h_{jk} (1-f_{ik})$$

$$R_{ij} = \sum_{k=1}^{9} W_{ij} r_k f_{ik}$$

$$R^{1}_{ij} = \sum_{k=1}^{9} W_{jk} r_k (1-f_{ik}) \qquad (7.1\text{-}8)$$

where:

H^{o}_{ij} = initial estimate of manhours at yard i on ship j

H^{1}_{ijk} = initial estimate of subsystem k manhours by subcontractors if ship j is built at yard i

R^{1}_{ij} = dollar amount of material to be supplied by subcontractors if ship j is built at yard i at present time

W_{jk} = weight of ship j which is classified in subsystem k

h_{jk} = manhours/ton labor estimate for subsystem k of ship j

r_k = dollars/ton material estimate for subsystem k at present prices

f_{ik} = historical fraction of subsystem k work done in-house by yard i

Of the three quantities R_{ij}, V_{ij}, and L_{ij}, these equations define R_{ij}. An expression for V_{ij} is given as

$$V_{ij} = R^1_{ij} + \sum_{K=1}^{9} c_{ik} H^1_{ijk} + \sum_{k=1}^{9} I_{ijk} \tag{7.1-9}$$

where:

c_{ik} = average hourly labor cost for component work in subsystem k

I_{ijk} = other indirect cost of including profit and overhead

The c_k will be taken as industry averages for the particular type of work required, and these may be estimated from historical data, I_{ijk} will be handled similarly. Alternatively one could estimate V_{ij} directly and derive the fraction of the labor and raw material it accounts for.

In order to compute labor costs for the yard itself, all labor is grouped together and an average rate per yard is used. The actual number of hours of labor at yard i will be different, in general, from the estimated baseline depending on the conditions existing in the yard at the given time. The variables selected are justified in the previous chapters. This is expressed as,

$$H_{ij} = \beta_{1i} H^{O}_{ij} Y_i^{-1} (1+\beta_{2i} T_i) \; A_i^{-1} (1+\beta_{3i} S_i)$$

$$\left(1 + \frac{\beta_{4i} V_{ij}}{L_{ij} + R_{ij} + V_{ij}}\right) E^{-1}_{ij} \left(1+\beta_{5i} \left| \frac{\Delta M_i}{\Delta t} \right| \right) \qquad (7.1\text{-}10)$$

where:

H_{ij} = predicted actual manhours at yard i in building ship j

H^{O}_{ij} = baseline manhour prediction

Y_i = employment level factor for yard i, as discussed below

T_i = turnover rate at yard i during time of construction expressed as fraction of workers who leave, plus fraction who join the yard, per year

A_{ij} = average time, in yards, since hire of work force at yard i, at the midpoint in completion of the work on ship j

E_{ij} = average experience time, in years, of first level supervision at yard i, at the midpoint in completion of the work on ship j

ΔM_i = change in total employment of yard (number of workers) in time period of length Δt preceding midpoint in completion of work on ship j

β_{ni} = parameters, to be determined

The yard employment factor, Y_i, recognizes that each yard has its own optimal employment "window" in which economies of scale can work to its advantage. At employment levels below this, lack of specialization and fixed costs start to make operation inefficient, while above this region the yard is not able to utilize its manpower efficiently due to overcrowding. The curve of Y_i is presumably concave downward, but we have chosen, for simplicity, to represent it as a piecewide

linear curve, which is greater than 0 at small employment levels. The level is less than one eventually as employment increases due to the physical inability of the facility to accommodate greater employment. Thus

$$
\begin{aligned}
Y_i &= 1 - \gamma_{1i}(M_{imin} - M_i), && M_{ij} \leq M_{imin} \\
Y_i &= 1, && M_{imin} \leq M_{ij} \leq M_{imax} \\
Y_i &= 1 - \gamma_{2i}(M_i - M_{imax}), && M_{io} \geq M_{ij} \geq M_{imax} \\
Y_i &= 0, && M_{ij} \geq M_{io}
\end{aligned}
\qquad (7.1\text{-}11)
$$

where:

M_{ij} = average employment level at yard i during time of building ship j

M_{imin}, M_{imax} = break points of yard efficiency, to be estimated or derived from data base

M_{io} = employment level at yard i which cannot be exceeded to be estimated or derived from the data base

γ_{ni} = parameters, to be estimated or derived from data base

If there are no data available for estimating M_{imin}, M_{imax}, and M_{io}, then these quantities can be estimated by knowledgeable people (Delphi technique).

The direct labor costs are then given at yard i by

$$L_{ij} = H_{ij}W_i \qquad (7.1\text{-}12)$$

where:

W_i = hourly wage rate in yard i

To summarize the cost estimation step of the model: the NAVSEA estimate of the basic manhours needed to build a

given ship is adjusted for specific conditions at a given yard at a given time. The adjusted manhour estimate and average wage are used to find labor cost. Material and subcontract estimates, the effect of inflation, and the effect of the learning curve (which will be empirically tested, with all the other efficiency factors) will be combined with the labor cost to find the direct cost of the ship. Overhead costs, profit (as determined by the price estimation step), GFE costs, and administrative costs will be added to the direct cost to find the total price to the Navy of the given ship.